GRID ARCHITECTURE, PLANNING AND DESIGN JOURNAL
GRİD MİMARLIK, PLANLAMA VE TASARIM DERGİSİ

Vol. 6, No. 1, 2023, 309-340 / Cilt 6, Sayı 1, 2023, 309-340 / DOI: 10.37246/grid.1115794

Effects of plaster choice on conservation of the original acoustical character of historical mosques

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Keywords

Historical plaster types; Mosque acoustics; Acoustic simulations

Abstract

The study aims to contribute acoustic characteristics of two monumental mosques in Western Anatolia: focusing on the change of material properties of the prayer hall and its effects on the perceived acoustical environment during history. Preserving the authentic auditory environments of historical mosques has great importance. Because the acoustical perception of the prayer hall affects users as much as their visual perception. Field measurements and acoustical simulations were held in two historical mosques with similar room volumes but different dome combinations to compare the present and probable original acoustical environments. The values of T30, EDT and STI are investigated by focusing on the change of plaster properties during restoration works. It is found that the original mortars could be differentiated for both cases and they might sound very different when the time they were first built. Acoustic documentation of such important historical monuments of Anatolia is quite a good contribution to the field of archaeoacoustics and historical conservation. However, the study focused on the change of material properties. The findings of the paper can raise the question; of whether it is possible to comment on the originality of materials of a historical space by measuring its current acoustical character.

Article Information

Received:
12.03.2022

Received in Revised Form:
15.12.2023

Accepted:
16.01.2023

Available Online:
30.01.2023

Article Category

Research Article

Highlights

- The acoustic perception of historical mosques affects users as much as their visual perceptions.
- It is found that the absorption coefficients of the plasters in the current state of the mosques are similar to today's cement-based contemporary mortars.
- The distributions of acoustical objective parameters become more uniform with historical plasters.

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Yelkenci Sert, F., & Yılmaz Karaman, Ö. (2023). Effects of plaster choice on conservation of the original acoustical character of historical mosques. *GRID Architecture, Planning and Design Journal*, 6(1), 309-340.

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Sıva türünün tarihi camilerin özgün akustik karakterlerinin korunmasına etkileri

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Anahtar Sözcükler

Tarihi sıva türleri; Cami akustiği; Akustik simülasyon

Öz

Çalışma, tarih boyunca camilerin malzeme özelliklerinin değişimi ve algılanan akustik çevre üzerindeki etkilerine odaklanarak Batı Anadolu'daki iki tarihi caminin akustik özelliklerine katkıda bulunmayı amaçlamaktadır. Tarihi camilerin özgün işitsel ortamlarının korunması büyük önem taşımaktadır. Çünkü ibadethanenin akustik algısı, kullanıcıları görsel algıları kadar etkilemektedir. Bu çalışmada, camilerin mevcut ve özgün akustik ortamlarını karşılaştırmak amacıyla benzer hacim boyutlarında, farklı kubbe kombinasyonlarına sahip iki tarihi camide saha ölçümleri ve akustik simülasyonlar yapılmıştır. Nesnel akustik parametreler olarak T30 (yansışım süresi), EDT ve STI değerleri, camilerin restorasyon çalışmalarında uygulanan sıvaların özelliklerinin değişimine odaklanılarak incelenmiştir. Çalışmanın her iki durumu için de özgün harçların ortamı farklılaştırılabileceği ve ilk yapıldıkları zaman ortamın kulağa çok farklı gelebileceği tespit edilmiştir. Anadolu'nun bu kadar önemli tarihi eserlerinin akustik belgeleme çalışmaları, arkeoakustik ve tarihi koruma alanlarına katkı sağlayacağı düşünülmektedir. Bununla birlikte, çalışma malzeme özelliklerinin değişimine odaklanmıştır. Makalenin bulguları "mevcut akustik karakterini ölçerek tarihi bir mekânın malzemelerinin özgünlüğü hakkında yorum yapmak mümkün müdür?" sorusunu ortaya koymaktadır.

Makale Bilgileri

Alındı:
12.03.2022

Revizyon Kabul Tarihi:
15.12.2023

Kabul Edildi:
16.01.2023

Erişilebilir:
30.01.2023

Makale Kategorisi

Araştırma Makalesi

Öne Çıkanlar

- Tarihi camilerin akustik algısı, kullanıcıları görsel algıları kadar etkilemektedir.
- Tarihi camilerin mevcut durumundaki sıvaların yutuculuk katsayılarının günümüz çimento esaslı harçların yutuculuk değerlerine benzer olduğu tespit edilmiştir.
- Tarihi sıvaların kullanıldığı hacimlerde nesnel akustik parametrelerin dağılımları daha düzgün olduğu görülmektedir.

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Yelkenci Sert, F., & Yılmaz Karaman, Ö. (2023). Sıva türünün tarihi camilerin özgün akustik karakterlerinin korunmasına etkileri. *GRID Mimarlık, Planlama ve Tasarım Dergisi*, 6(1), 309-340.

ACOUSTICS IN HISTORICAL MOSQUES

Mosques are sacred spaces and most of the time prayer halls are built with high attention and use of the most innovative techniques of the era and place where the mosques were constructed. They have been built not only to meet the needs of prayer but also they are expected to have an impressive effect on the people. Dome, which is covering the main prayer hall with various combinations, is one of the most recognizable elements of mosque architecture of the Ottoman era and many examples that differ in size built throughout the history of Anatolia. Most of these historical mosques are still in use and they are also important elements of the history of architecture.

Islam religion accepts that some rituals are appropriate to do with the congregation. For this reason, large volumes are needed to accommodate large groups of people. Most mosques were covered with a combination of concave surfaces such as dome, half-dome, dome-vault or many domes to obtain the volume needed. Large volumes and concave surfaces are expected to cause long reverberation time that may negatively affect prayer hall acoustical conditions. However, the materials used in mosques, such as carpets, have some roles to reduce reverberation compared to churches. Materials of the large wall surfaces also are expected to affect the acoustical characteristics (Kleiner, et al., 2010; Sü Gül, 2019).

The acoustical perception of the prayer hall affects users even more than their visual perception to feel the volume and the divine feeling during religious rituals (Abdelazeez, et al., 1991; Grabar, 1983). In this context, mosques are important subjects of literature on acoustics (Abdou, 2003; Carvalho and Monterio, 2009, Kayılı, 1988). Some studies on mosques focused on acoustic evaluations and comparisons in mosques (Elkhateeb and Ismail, 2007; Elkhateeb, et al., 2015; Ismail, 2013). Most of the studies investigate mosques through historical and modern examples by measurements and acoustical simulations (Sü and Yılmazer, 2008; Sü Gül, et al., 2014; Topaktaş, 2003) Some studies focus on the comparison between the acoustical environment of different sacred spaces (Kleiner, et al., 2010, Wetiz, et al., 2002). Some studies describe the importance of sound in religious buildings as a part of intangible cultural heritage (Grabar, 1983; Ergin, 2008; Suarez, et al., 2015). Ergin emphasizes the importance of the acoustical environment and underlines the lack of studies in her paper. According to Ergin (2016); "*In spite of the significance of sound in Islamic cultures—whether in the form of Qur'an recital, the call to prayer, or poetry recital—historians of Islamic architecture* *generally have neglected acoustic qualities of the built environment, probably because even in the visual realm so much basic historical research remains to be done*" (Ergin, 2016). Some experts are interested in acoustic renovation/improvement and acoustic design studies of mosques (Abdelazeez, et al., 1991; Hamadah and Hamouda, 1998; Sü Gül and Çalışkan, 2013).

Evaluation of the acoustical environments of sacred spaces is one of the important issues in acoustic studies. Most studies on mosque acoustics use optimum ranges of objective acoustic parameters, which are improved for the speech rooms, due to the lack of certain optimum parameter ranges specifically developed for mosques. However, the prayer hall is quite a challenging environment where both speech and musical rituals are held and also where the feeling of sacred space should be kept. In this context, some researchers focused on developing optimum value ranges of acoustic parameters and design criteria for mosque acoustics (Prodi and Marsilo, 2003; Orfali, 2007; Utami, 2005). In some studies, acoustic parameter values were analyzed for the mosque models with different plan schemes to draw attention to the effects of early design decisions on the acoustics of the environment for future mosque projects (Abdou, 2003; Eldien and Qahtani, 2012). Reverberation time, sound pressure level distribution and sound transmission index which have effects on speech intelligibility of volumes have been evaluated in some studies (Sü and Yılmazer, 2008; Suarez, et al., 2004).

Architectural features are also another parameter that affects the acoustical environment. Dimensions, plan typology and ceiling structure with dome are the main architectural elements that constitute the acoustical environment of the prayer hall as well as building materials and construction techniques in historical mosques (Kitapçı and Çelik Başok, 2021; Yelkenci Sert and Yılmaz Karaman, 2021). It can be said that the dome geometry and excessive volume of the prayer hall are important factors in the acoustical environment of historical mosques.

There have been changes in the architecture and/or material properties of mosques throughout their history such as extensions or interventions because of structural and/or material deteriorations, and function changes. These interventions that were made at different times have effects on both the visual and acoustical characteristics of the original state of the prayer hall. For that reason, research in archaeoacoustics has been focused on ancient worship spaces, since it is possible to study the acoustic environment of ancient worship spaces with the help of simulation tools (Dordevic, et al., 2019; Omar, et al., 2020; Alberdi, et al., 2021) and to revive the sound of worship spaces that disappeared or had major transformations throughout history (Karabiber, 2000; Suárez, et al., 2018; Tanaç Zeren, et al., 2016). In addition, the modern use of an ancient building may require function change and to meet the needs of the new function acoustical interventions would have to be considered in some cases (Postma and Katz, 2015).

There are many acoustic studies on historical mosques as seen in the literature review. However, a few studies examine historical plaster samples and their effects on acoustics environments. This study is aimed to fill this lack in the literature to show the effects of original plasters on the auditory environment in the conservation studies of historical mosques.

DEFINITION OF THE STUDY

The selection of surface materials is one of the main criteria that builds the acoustical environment of rooms. Additives within the mortar paste and the thickness of the plaster layer affect the properties of surfaces. Plasters used on the walls protect the buildings from deterioration and provide durability and most surfaces are covered with plaster interiors of historical mosques (İpekçi, et al., 2019). As mentioned before, some structural and architectural renovations are inevitable during the lifespan of historical mosques. They can change the original acoustic environment of the prayer hall, in which good intelligibility for speech and music and/or preventing higher background noise levels is an important issue. These issues are dependent on the sound absorption coefficient of plasters because of the big amount of plastered surface area (Bozkurt and Demirkale, 2019).

In this context, the study aims to start a discussion on whether the replacement of original plasters can change the original acoustical perception of historical mosques or not. In other words, the study focuses on the change of mortar properties and its effects on the acoustical environment of the prayer hall. This question is an outcome of previous studies (Yelkenci Sert, 2021; Yelkenci Sert and Yılmaz Karaman, 2021) that held around 30 historical mosques built in Western Anatolia. During the calibration process of simulation models of mosques, it is found that the absorption coefficients of the plasters in the current states of the mosques are similar to contemporary cement-based mortars instead of lime-based mortars. Also in a recent study, it is found that absorptive materials can significantly change the sound energy decay rates within Süleymaniye Mosque and Hagia Sofia Mosque depending upon their applied surface areas (Sü Gül, 2019).

To achieve this goal, literature on historical mortars that are used in traditional architecture is reviewed and sound absorption characteristics of historical mortars are collected to simulate probable original acoustics of prayer halls. And the methodology of literature on archaeoacoustics is followed which can be summarised as;

- field measurements to evaluate the acoustical performance of the current properties of the room;
- the creation of an acoustical model of the room, which is calibrated according to measurement data and,
- changes in the room properties to restore the room to the original state or/and determine the effects of different acoustical treatments to make acoustical improvements, respectively (Sü Gül, 2019; Omar, et al., 2020; Postma and Katz, 2015).

Field measurements were held in two historical mosques built with similar room volumes. The prayer halls of the mosques were modelled and calibrated according to measurement data.

The values of objective room acoustic indicators are investigated by comparing the present and probable original states of the mosques. And it is considered that the original mortars, which were lime-based, could be differentiated in terms of absorption characteristics for both cases of the study. In this context, the study aims to find how they might have been sound when they were first built by the use of lime-based mortars. In conclusion, it is found that keeping the content of the original plaster is an important part of preserving not only the structure but also the auditory perception it used to have.

ACOUSTICAL PROPERTIES OF HISTORICAL PLASTERS

There are some studies on historical mortars and their features in the literature, although the number of studies dealing with their acoustical characteristics is limited.

Most historical mortars are lime-based and include natural fibres originally (Kolay, 2016). Portland cement, which is currently in use as the main ingredient of contemporary mortars has different structural characteristics in comparison to lime. The difference between lime mortar and portland cement mortar, generally used in buildings, causes condensation differences, cement mortar's mechanical strength and elasticity are higher than the lime, and lime has macro gaps while portland cement has micro gaps (Ersen, et al., 2013).

Properties of plaster mixtures that were used in historical buildings are described in the report for the Directorate General of Foundations of the Republic of Turkey to be used in the restoration works. According to this report, the types of historical mortar mixtures are based on hydraulic lime binder, hydrated lime binder and hydrated lime binder with pozzolan additive. These mortar mixtures are expected to be used in the restoration process of historical buildings (Ersen, et al., 2013).

Bozkurt and Demirkale (2019) investigated the sound absorption coefficients of the historical plasters. In this context, they studied three different mixtures based on the hydraulic lime binder, the hydrated lime binder, and the hydrated lime binder with pozzolan additive with the thickness of 3 cm, 6 cm, 9 cm, and 12 cm by the report for the Directorate General of Foundations of the Republic of Turkey (Bozkurt and Demirkale, 2019). Absorption coefficients of these plaster mixtures are used to find out the probable original state of the mosques' acoustical conditions.

Tavukçuoğlu et al. (2011) studied historical lime plaster layers collected from Turkish Hammams for dry, damp, and wet conditions. They found sound absorption coefficients of historical plasters higher than oil-painted cement-based plasters. (Tavukçuoğlu, et al., 2011).

Kayılı (1988) mentions four types of plasters that were collected from historical mosques during the restoration works. According to the study, the replacement of the original "horasan" plasters with hemp fibres caused the increase of RT, especially in mid frequencies within the mosque volumes (Kayılı, 1988).

In the study of Sü Gül (2019), the effects of the historical plasters on the acoustic environment were investigated through two monuments: Hagia Sophia and Süleymaniye Mosque (Sü Gül, 2019). The examples of the paper have 150000 m3 and 75000 m3 volumes respectively and they are supposed to have a different acoustical character with their giant volumes in comparison to the 4000 m3 volumes of this study. But interventions of the plasters on wall surfaces during the restorations are supposed to be similar.

It is also found that the original mortars were replaced with cement-based ones during the restoration processes of the Süleymaniye Mosque. And cement-based plasters were replaced with lime-based plasters in the last restoration works, however acoustic evaluations showed that this replacement may not be enough to turn the mosque into its original state (Sü Gül, 2019).

During the last restoration process, it was seen that the plasters of the Sultan Mosque had many alterations as a result of many earthquakes (the last one was in 1999) that damaged the mosque (Erdoğan, 2006). According to the documents, Yeni Mosque was renovated in 1665, 1887 and 1961 (Aslanoğlu, 1978). In addition, it is found that the absorption coefficients of the plasters in the current state of the mosques are similar to cement-based contemporary mortars. And it is considered that the original mortars could be replaced in both cases and they might sound very different from when they were built.

In Table 2, the sound absorption coefficients of the plasters from the literature are listed. These values of plasters are applied to acoustical models of the two prayer halls and each one is modelled, and results are compared to the current states of the rooms.

According to Table 1; P1 (Plaster No:1) shows the current plaster used for the calibration of acoustic models of this study. P2, P3 and P4 are also current plaster coefficients obtained from the calibration process of similar studies on mosque acoustics. Koutsouris et.al (2016) used the plaster (P2) with absorption coefficients that are shown in Table 2 for simulation models of Selimiye Mosque, one of the masterpieces of Architect Sinan (Koutsouris, et al., 2016). P3 is the current plaster that was used for the calibration of the acoustic model of Suleymaniye Mosque, by the field measurements after the last restoration works (Sü Gül, 2019). Topaktaş (2003) used the plaster (P4) with absorption coefficients of 0.05 for 500 Hz, and 0.04 for 1000 Hz for simulation models of four mosques (Topaktaş, 2003). There is not a significant difference in sound absorption characteristics among P1, P2, P3 and P4.

Other plaster types (between P5- P17) are defined as historical plasters that are quite absorptive in comparison to current plasters (Tavukçuoğlu, et al., 2011; Bozkurt and Demirkale, 2019). Sound absorption coefficients of these historical plasters were applied to the Odeon models of Yeni Mosque and Sultan Mosque.

Table 1 - Sound absorption coefficients of different plaster types collected from the literature; (P1, P2, P3, P4; Current plasters on mosques, P5; historical plaster, P6, P7, P8, P9; mortar mixture based on the hydraulic lime binder, P10, P11, P12, P13; mortar

Plaster types from literature	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
P1 – Current plaster	0.08	0.07	0.07	0.08	0.09	0.10
P2 – Current plaster (Koutsouris, et al., 2016).	0.02	0.02	0.05	0.07	0.10	0.11
P3 – Current plaster (Sü Gül, 2019).	0.13	0.09	0.07	0.05	0.03	0.04
P4 – Current plaster (Topaktaş, 2003)	0.14	0.10	0.05	0.04	0.04	0.03
P5 – Historical plaster, approx. 30 mm thick, 2 layered lime-based plaster collected from the building (Tavukçuoğlu, et al., 2011)	0.10	0.12	0.25	0.29	0.33	0.33
P6 – Historical plaster (mortar mixture based on the hydraulic lime binder 30 mm) (Bozkurt and Demirkale, 2019)	0.02	0.03	0.04	0.15	0.19	0.20
P7– Historical plaster (mortar mixture based on the hydraulic lime binder 60 mm) (Bozkurt and Demirkale, 2019)	0.01	0.02	0.07	0.19	0.19	0.12
P8– Historical plaster (mortar mixture based on the hydraulic lime binder 90 mm) (Bozkurt and Demirkale, 2019)	0.01	0.02	0.25	0.12	0.21	0.15
P9– Historical plaster (mortar mixture based on the hydraulic lime binder 120 mm) (Bozkurt and Demirkale, 2019)	0.02	0.03	0.43	0.08	0.19	0.12
P10– Historical plaster (mortar mixture based on the hydrated lime binder 30 mm) (Bozkurt and Demirkale, 2019)	0.03	0.07	0.13	0.20	0.26	0.18
P11– Historical plaster (mortar mixture based on the hydrated lime binder 60 mm) (Bozkurt and Demirkale, 2019)	0.04	0.10	0.19	0.18	0.25	0.19
P12– Historical plaster (mortar mixture based on the hydrated lime binder 90 mm) (Bozkurt and Demirkale, 2019)	0.05	0.11	0.20	0.16	0.26	0.22
P13– Historical plaster (mortar mixture based on the hydrated lime binder 120 mm) (Bozkurt and Demirkale, 2019)	0.07	0.16	0.20	0.20	0.38	0.37
P14– Historical plaster (mortar mixture based on the hydrated lime binder with pozzolan additive 30 mm) (Bozkurt and Demirkale, 2019)	0.02	0.03	0.07	0.17	0.18	0.15
P15– Historical plaster (mortar mixture based on the hydrated lime binder with pozzolan additive 60 mm) (Bozkurt and Demirkale, 2019)	0.01	0.06	0.22	0.11	0.22	0.17
P16– Historical plaster (mortar mixture based on the hydrated lime binder with pozzolan additive 90 mm) (Bozkurt and Demirkale, 2019)	0.02	0.06	0.19	0.08	0.23	0.19
P17– Historical plaster (mortar mixture based on the hydrated lime binder with pozzolan additive 120 mm) (Bozkurt and Demirkale, 2019)	0.05	0.16	0.20	0.12	0.27	0.37

ACOUSTICAL ANALYSIS OF YENI MOSQUE AND SULTAN MOSQUE

In this section, it is aimed to observe the effects of the interventions on the acoustic environment within the scope of the study. First, the architectural features in the current state of the mosques, then acoustical field measurements and simulation processes are described.

Architectural features of cases

In the study, two important mosques, Yeni Mosque and Sultan Mosque, which were built in the 16th century, in two important centres of the Ottoman Empire are evaluated (Figure 2). They are quite moderate examples in terms of size by comparing the mosques that were built in İstanbul, the capital of the Empire, during the same period, however, they are important elements of the history of architecture.

According to the information obtained in the literature, the Yeni Mosque was built by Behram Kethüda during the reign of Sarı Selim at the end of the 16th century in Tire, one of the important centres (sanjak) of the Ottoman Empire at those times (Aslanoğlu, 1978). The mosque's sanctuary has a square plan of 15 x 15 m, covered with a single central dome (Figure 1) and it has the biggest volume among the ancient mosques built around Tire. This form of the prayer hall has been repeated for both historical and contemporary mosque architecture, especially for the moderate examples in smaller cities. The central dome was settled on a hoop, which is 150 cm in height and has 8 window openings (Figure 3). The thickness of the plastered masonry walls reaches 180 cm. Load transfer was implemented from the central dome to the walls through pendentives and squinches that are placed in the corners of the prayer hall. There is a wooden maksoorah carried by wooden pillars above the entrance section. The mihrab and pulpit elements of the mosque are made of marble.

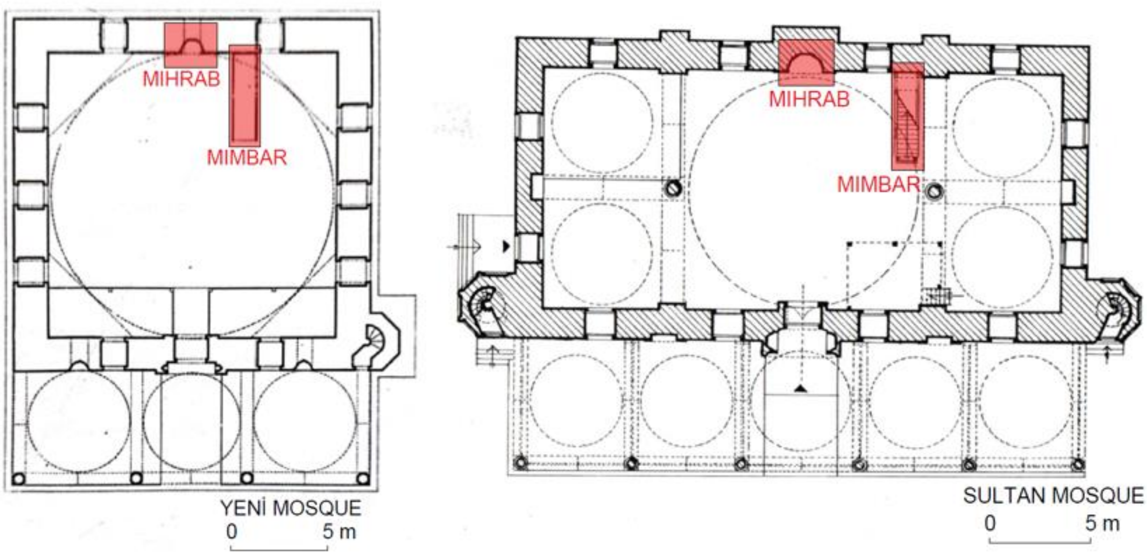


Figure 1 - The plans of Yeni Mosque (left) and Sultan Mosque (right) (Aslanoğlu, 1978; Acun, 1999).

Sultan Mosque, built in the 16th century, is one of the most important historical buildings in Manisa. Manisa, whose history dates back to the Palaeolithic period, is an important settlement named Magnesia and Sipylum in the antique period in Anatolia. Manisa had an important position in the historical period of the Ottoman Empire, not only by being one of the oldest settlements but also by being a sanjak, where princes were educated and managed. As a result, many important buildings were built in Manisa, such as mosques, libraries, schools, Turkish baths, and commercial buildings (Acun, 1999).

Figure 2 - Exterior views of Yeni Mosque (left) and Sultan Mosque (right).

Sultan Mosque has a transverse rectangular plan schema with a volume of approximately 4000 m^3 (Figure 1). It is covered with a domed composition consisting of the main dome of about 22.5 m in height and two small domes covering side aisles on two sides. The main dome of the mosque has a diameter of 11.5 m. The smaller domes which are sitting on octagonal hoops have diameters of 5 m. The transitions from walls to domes are provided with pendentives. The mosque has a floor area of 312.5 m^2. The part where the transition elements to the dome are located is enclosed by a square prism hoop from the outside. The hoop of the dome supported by buttresses is placed on it. Thus, the central dome gives the impression of sitting on a two-storey hoop. The main worship area is connected to the side spaces by two arches that are stepping on pillars (Figure 4).

Figure 3 - Main dome and transition elements in the Yeni Mosque.

Figure 4 - Main dome and arches in the Sultan Mosque.

Table 2 - The architectural features of cases.

	Yeni Mosque	**Sultan Mosque**
Location	Tire, İzmir	Manisa
Year of construction	16th Century	1522 (16th Century)
Type of roof covering	single masonry domed	multi masonry domed
Plan dimensions	15x15 m	25.75x11.65 m
Height of mosque	13 m	11.8 m
Volume	3442 m^3	4000 m^3
Type of plan	Square	Rectangular
Capacity	291	375
Volume per person	11.83 m^3	10.67 m^3

Dimensions, proportions and geometry affect the acoustical environment of the prayer hall as well as the finishing materials of surfaces. The architectural features of the cases are summarized in Table 2. Both of the mosques were built in the same period with similar capacity and room volume with plastered wall surfaces. Main prayer halls differ in terms of plan geometry and dome configuration depending on the planning scheme. In Sultan Mosque, the prayer hall was formed under the central dome and side aisles connected by two arches on both sides, while Yeni Mosque has a single space under the central dome.

Although mosques have sustained their genuine form and function, some interventions can be observed inside. For example, the original plasters on walls have been changed during the time like other Ottoman mosques. Furthermore, the southeastern part of the Sultan Mosque has been raised 50 cm from the ground. Nowadays, this part is isolated from the main worship area by reflective panel elements. In the Yeni mosque, walls were covered by discordant ceramic tiles approx. 120 cm high (Figure 5).

Figure 5 - Ceramic coverings on the walls of Yeni Mosque (left) and dividing panels in the Sultan Mosque (right).

Documentation methodology

The methodology which is defined in section 2 and found to be used in most of the studies on archaeoacoustics is followed in this paper. First, field measurements were held to evaluate the acoustical performance of the current properties of the prayer halls of the mosques. Then, acoustical models of the rooms, which are calibrated according to measurement data, were made to restore the prayer halls to their possible original state. To identify the changes in acoustical conditions of the prayer hall depending on the possible replacement of original mortars on wall and dome surfaces; plaster types are changed on the models and results are compared with the current conditions. In this context, the first part of the study consists of onsite acoustical measurements. The second part of the study contains computer simulations by the ODEON Combined v16 Room Acoustics Software Program launched by the Technical University of Denmark. The acoustical evaluations are carried out by acoustical parameters defined in ISO 3382-1, 2010. Absorption coefficients of historical materials are obtained from the literature review as defined in the previous chapter and listed in Table 2.

Field Measurement Conditions

Field tests were carried out by a team of two people for both mosques in unoccupied conditions. In assessing room acoustic parameters, field measurements were held by ISO 3382-1,2010 (3382-1, 2010). An Omni power sound source was used for the signal generation with a power amplifier (The brand and model of the equipment were B&K 4292-L and Type 2734-A respectively.) The impulse responses at various measurement points were captured by the B&K omnidirectional microphone of the handheld analyzer (B&K-Type 2250-A). Both the microphone and analyzer were calibrated before measurement. DIRAC Room Acoustics Software v.6.0 was used for both generating different noise signals and getting the measured impulse response data for each receiver position.

Before measuring the parameters of room acoustics, background noise levels are measured inside and outside of the prayer halls. And this information is used in both field measurements and acoustical simulations. Daytime average background noise levels (Laeq) obtained during field measurements have been obtained as 45 dB for the Sultan Mosque and 31.5 dB for the Yeni Mosque.

The sound signal was configured as at least 45 dB higher than the noise in all octaves to ensure the reliability of results related to decay parameters. Tested signals were E-sweep and MLS, and up to pre-results impulse response lengths were set longer than RT of the rooms for all frequencies. There weren't significant differences depending on the signal type, therefore MLS signals were generated by the system used for the measurements. The sound source (S1) was placed in front of the mihrab at a height of 1,5 m simulating the Imam, and the receiver points (R1,2,3…) were placed at a height of 0,85 m. simulating prayer's sitting position (Figure 6- 7).

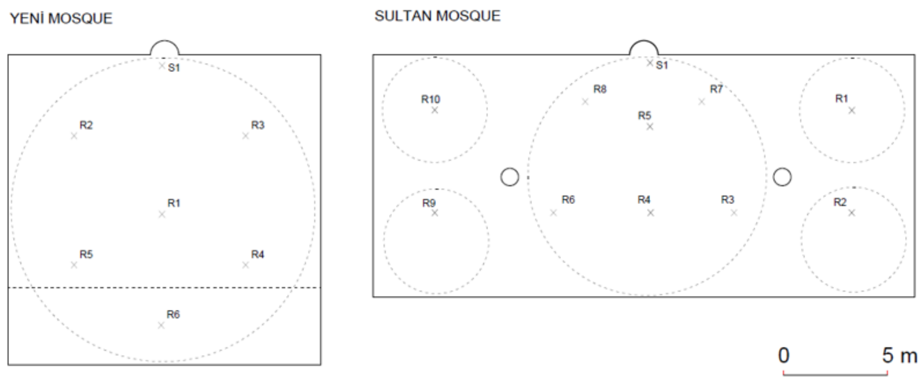


Figure 6 - The locations of sound sources (S) and receiver points (R) in the mosques.

Figure 7 - The positions of sound sources and receiver points in the field measurements (left photo from the Yeni Mosque; right photo from the Sultan Mosque).

Acoustic Simulation Conditions

The acoustical simulations of two monumental mosques are carried out to investigate the original acoustic state of the prayer halls. The geometrical models of mosques based on detailed architectural drawings in the literature and room dimensions were also checked with the architectural documentation by the researchers during the fieldwork. Mosques were modelled with

SketchUp2020, which is compatible with room acoustics software, ODEON. Ray tracing simulations were carried out by ODEON Combined v.16 Room Acoustics Software (Figure 8-9).

The measurement scenario, used for the field measurements was repeated for the acoustical models. The Imam as a sound source was placed in front of the mihrab at 1.50 m from the floor level. Therefore, the 10 receiving points in Sultan Mosque and 6 receiving points in Yeni Mosque were set at a height of 0.85 m as seating level (Figure 8-11).

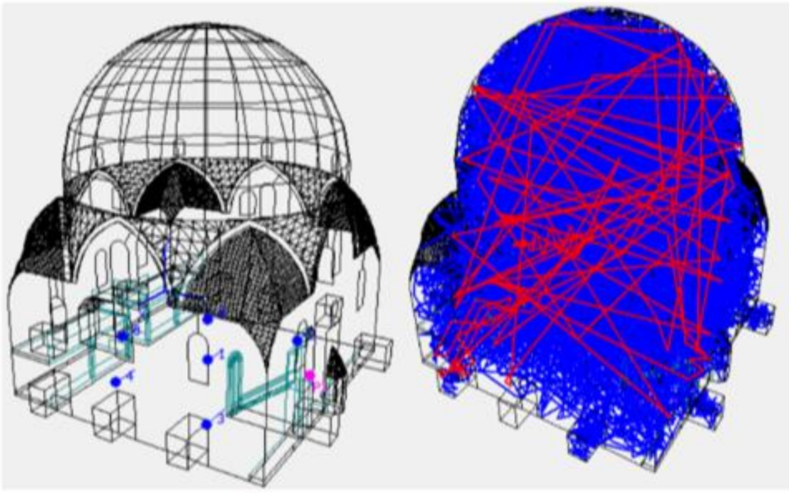


Figure 8 - ODEON model of Yeni Mosque and sound escape analysis.

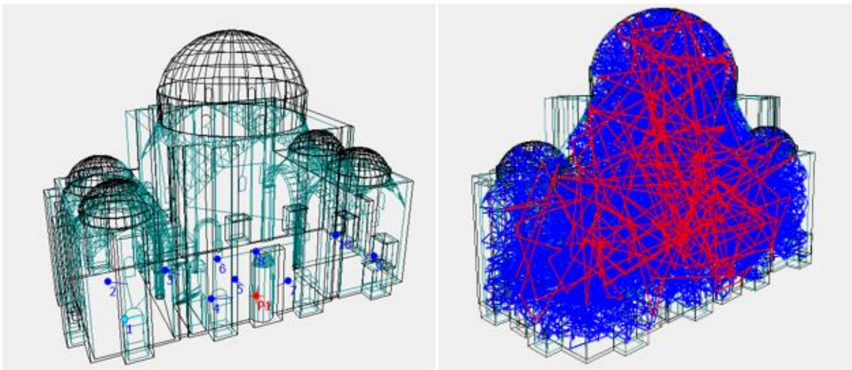


Figure 9 - ODEON model of Sultan Mosque and sound escape analysis.

Figure 10 - 3D displays of Yeni Mosque's ODEON model (from S1, R5, and R4 positions).

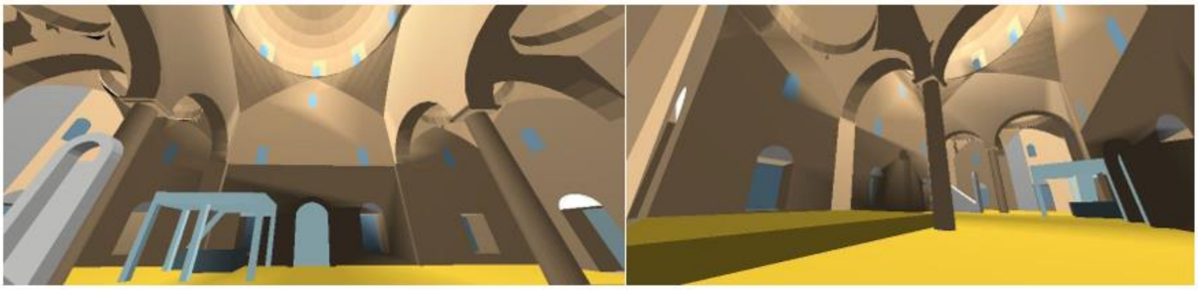


Figure 11 - 3D displays of Sultan Mosque's ODEON model (from S1 and R10 positions).

The models were calibrated and further utilized according to the original states. The calibration process started with selecting absorption coefficients for the surface materials in the geometrical model from available databases and/or literature. Sound absorption and scattering coefficients of materials were explored to adjust the mean reverberation parameters to within 1 JND of the measured value (Sü Gül and Çalışkan, 2013; Postma and Katz, 2015).

Table 3 - Material properties used for the ODEON model. (1 optimized plaster values for both mosques).

	Absorption Coefficient						Surface Area (m²)	
locations	**125 Hz**	**250 Hz**	**500 Hz**	**1 kHz**	**2 kHz**	**4 kHz**	Yeni M.	Sultan M.
Wall, transitions & dome surfaces[1]	0.08	0.07	0.07	0.08	0.09	0.10	1198.3	2214.4
floor carpet (Cahrisma, 1999)	0.02	0.03	0.07	0.19	0.39	0.62	261.78	307.7
window	0.18	0.06	0.04	0.03	0.02	0.02	55.83	58.1
wooden surfaces	0.42	0.21	0.10	0.08	0.06	0.06	78.64	78.6
marble	0.01	0.01	0.01	0.01	0.02	0.02	53.32	63.3
curtains	0.03	0.12	0.15	0.27	0.37	0.42	15.67	-
Steel trapeze profile	0.3	0.25	0.20	0.10	0.10	0.15	9.32	-

The walls of mosques are plastered, and the floor is covered with carpet as usual. In the acoustical model, the sound absorption coefficients data for materials such as marble, glass surfaces, and ceramic tiles are defined in most sources and these surfaces are mostly reflective and cover smaller areas by comparing the wall, ceiling and floor surfaces. On the other hand, absorptive materials like carpet on the floor can especially affect the room's properties. For that reason, the selection of carpet is an important issue to regulate the effect of high reverberant volumes by reflective materials. In the study, the absorption coefficients for carpets are obtained from the measurements made for the CAHRISMA project and applied as a flooring material to calibrate the simulation model by fieldwork (Cahrisma, 1999). Another distinctive material is plaster, which covers all the wall surfaces as well as the domes and transition elements of the roof structure. Current plaster is found quite a reflective material by the calibration process, and material properties are shown in Table 3.

It can be concluded that the estimated sound absorption performances of plasters that exists today and possibly changed in previous restorations of mosques, were obtained through the calibration process. The model has been calibrated for unoccupied conditions as the same with field measurements. The difference between T30 values of simulated and measured halls (Table 4) is kept under a range of 5% (1 JND) which is suggested in the previous works in the literature (Alberdi, et al., 2021; Postma and Katz, 2015).

Table 4 - T30 results of measured and simulated (present state) mosques.

T30 (s)		125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
Yeni Mosque	Dirac	4.40	4.58	3.53	3.16	2.35	1.59
	Odeon	4.61	4.45	3.56	3.06	2.31	1.57
JND (5%)		**0.22**	**0.23**	**0.18**	**0.16**	**0.12**	**0.08**
Difference		**0.21**	**-0.13**	**0.03**	**-0.10**	**-0.04**	**-0.02**
Sultan Mosque	Dirac	3.88	4.13	3.45	2.66	2.11	1.54
	Odeon	4.02	4.18	3.46	2.68	2.02	1.53
JND (5%)		**0.19**	**0.21**	**0.17**	**0.13**	**0.11**	**0.08**
Difference		**0.14**	**0.05**	**0.01**	**0.02**	**-0.09**	**-0.01**

Acoustic evaluation according to the current state of cases

In this part, the acoustic environments of the current conditions of both mosques were evaluated according to values of parameters obtained by the acoustic measurements. In the evaluations, average values of objective parameters are preferred to use to make the subject more understandable for experts from other disciplines. The possible original acoustic environments of the mosques were discussed in the next section, via acoustical models created with historical plaster samples to simulate possible original states of the prayer halls.

As stated in the literature review, describing the desired acoustical environment is quite a challenging issue because of not only the variation of rituals but also the need for a feeling of “sacred space” inside. From the point of view of reverberation time, high values in mosques have negative effects on speech intelligibility, while low values may cause mosques perceived as “dry” during religious rituals. What is expected from the acoustic environment of mosques is to provide a level of reverberation that creates the desired "divine" environment for prayers who use mosques during religious rituals.

The measured reverberation time (T30) values of mosques are shown in Figure 12. The field measurement results show that both mosques have very high T30 values in comparison to optimum values defined by previous studies on mosque acoustics (Kayılı, 1988; Orfali, 2007)

(Kuttruff, 2009). It is seen that these mosques are not suitable for speech activities but they can provide a desirable volume for liturgical rituals. In addition to this, it is observed that T30 values at 250 Hz are higher than mid frequencies. However, T30 values of low frequencies closer to optimum ranges are important for the intelligibility of speech (Imam's orders).

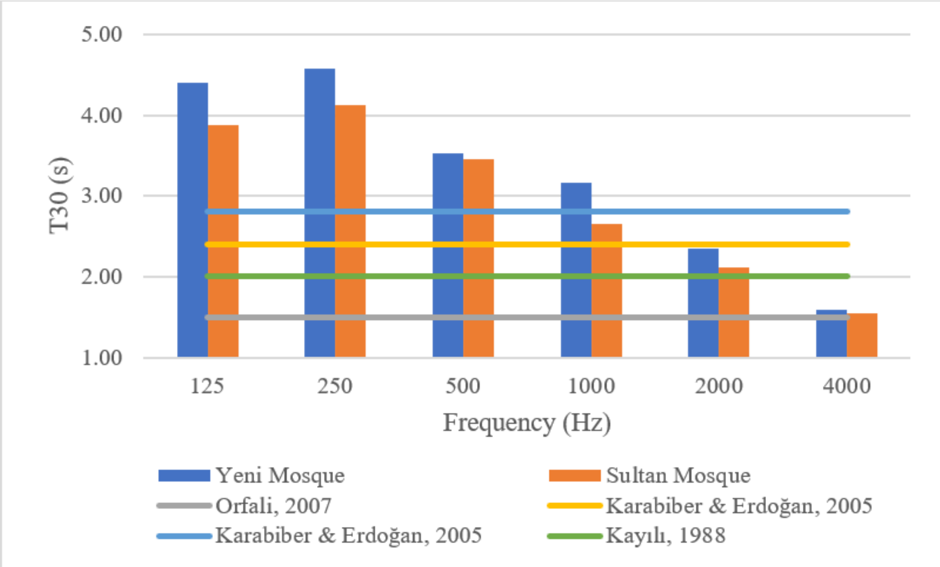


Figure 12 - T30 results from the measured data for the current states of both mosques.

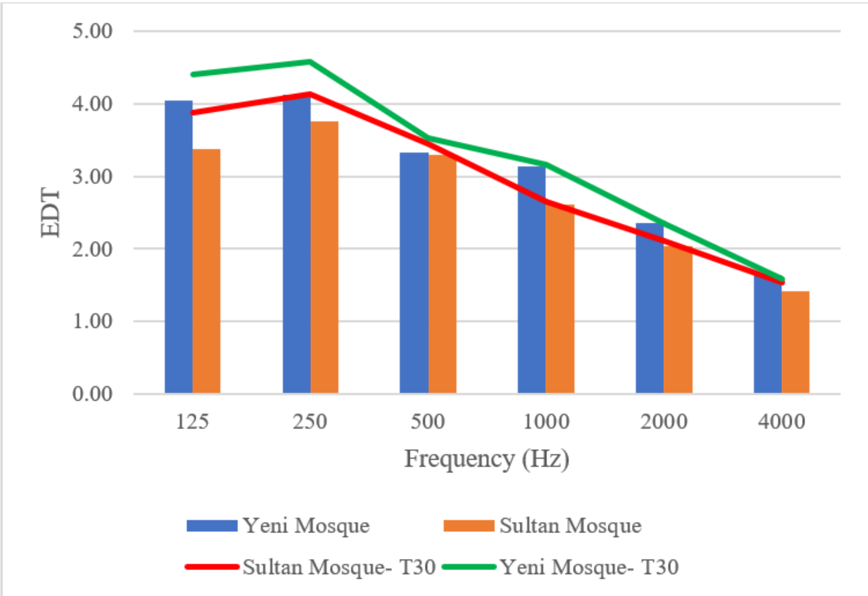


Figure 13 - EDT results from the measured data for the current states of both mosques.

For providing acoustical quality in volumes, the EDT parameter values should be within ±10% of reverberation time (RT) (Mehta, Johnson, & Rocaford, 1999). If the T30 and EDT graph slopes are similar in the examined mosques, it can be said that the sound distribution in the volume is homogeneous and regular. Homogeneous sound distribution is an important requirement for achieving the desired intelligibility in volume acoustics. Sound decay within the volume is found quite uniform in both cases as EDT and T30 values are found very close (Figure 13). EDT is also another instance of the reverberant field in the prayer halls describing the early reflections.

During the Friday sermons, the intelligibility of speech becomes important. In this context, D50 and speech transmission index (STI) parameters are used to evaluate speech intelligibility. For volumes where speech is desired to be understood well, the sound signal should be preserved in the frequency range effective for the speech function. Moreover, for speech intelligibility, it is expected that the audio signal will not be damaged by high background noise and long reflection time (Sü Gül and Çalışkan, 2013).

The results of D50 are presented between 125 Hz and 4000 Hz in Figure 13. D50 is related to speech intelligibility and needs to be greater than 50%, however, D50 values that are higher than 20% are considered sufficient for speech intelligibility in some of the studies (Kuttruff, 2009). In the study, D50 (Definition) values obtained lower than 50%, however, the values are higher than 20% for almost all frequencies (Figure 14). Values of D50 are found lower at the receiver points that were placed behind the mimbar, which are quite big elements by comparing the dimensions of the interior space, for both Sultan and Yeni Mosques.

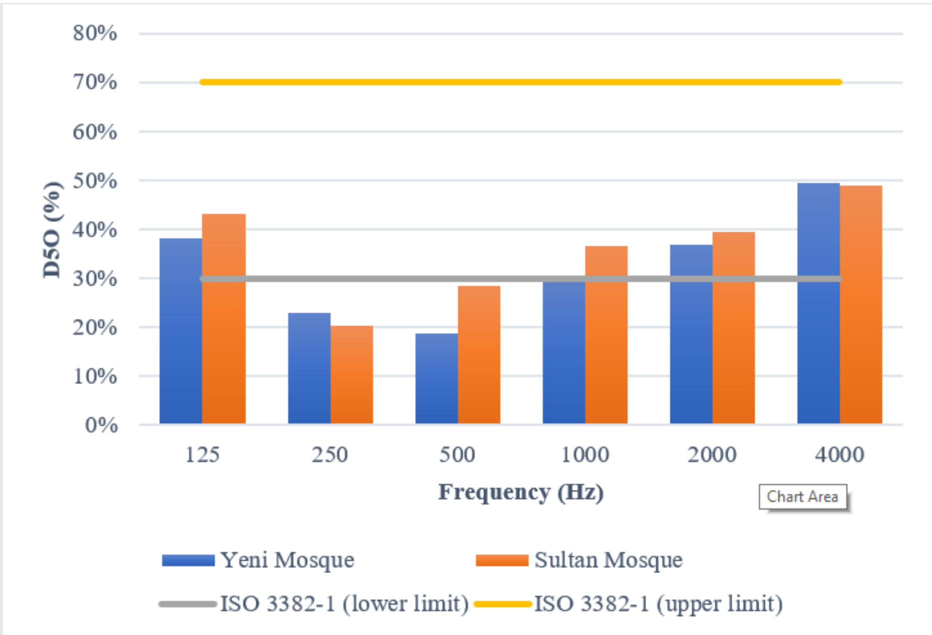


Figure 14 - D50 results from the measured data for the current states of both mosques.

Clarity is defined as the logarithmic ratio in dB of the energy of the sound arriving in a closed volume within the first 80 ms to the energy of the sound arriving at the receiver after this period. For clarity of both speech and music, it is accepted to an optimum range for C80 can be between-4, and +4 (Long, 2014). In the literature, the range of 0, -4 dB in musical activities and -2, +2 dB in speech activities are considered the optimum ranges (Sü Gül, et al., 2014). However, it is stated that the feeling of spaciousness and sacred feeling surrounds the listeners in the volumes with the optimum C80 values between -2 and 0 dB for musical activities (Kitapçı and Çelik Başok, 2021).

Average C80 values for 500 Hz and 1000 Hz are -5.4 dB, -2.88 dB respectively in Yeni Mosque, -3.31 dB, -1.35 dB in Sultan Mosque. It can be said that the Sultan Mosque is in the more appropriate range in terms of C80 values compared to Yeni Mosque (Figure 15).

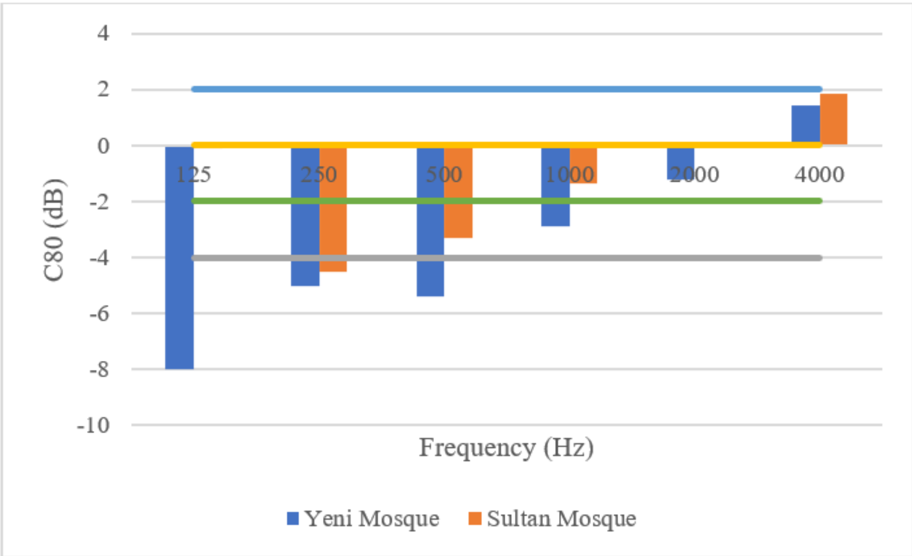


Figure 15 - C80 results from the measured data for the current states of both mosques. (---, ---; optimum C80 values for music, ---, --- ; optimum C80 values for speech (Gül, Çalışkan & Tavukçuoğlu, 2014)

STI is an objective parameter used to measure speech intelligibility in a closed volume. STI is evaluated in the range of 0 and 1. The optimum values for STI are defined as; 0 – 0.32 as bad, 0.32-0.45 as poor, 0.45-0.60 as fair, 0.60-0.75 as good, 0.75 – 1.0 as excellent.

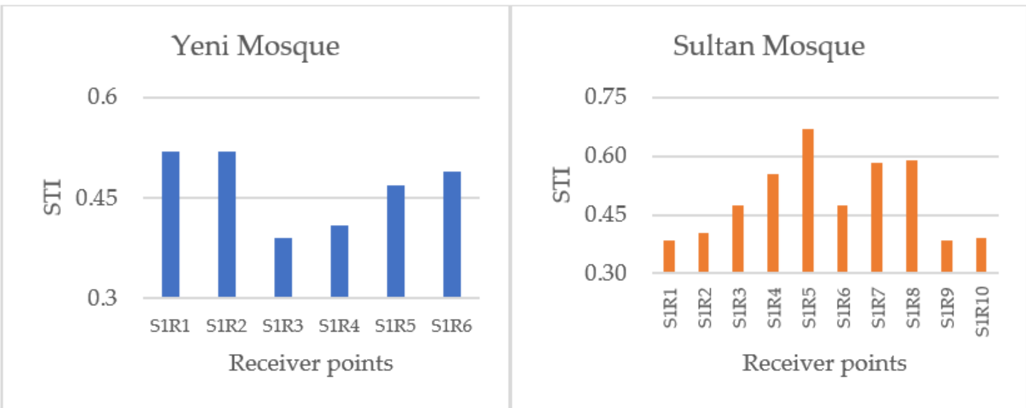


Figure 16 - Measured STI values for all receiver points in the case of mosques (Bad 0 - 0.32, Poor 0.32 - 0.45, Fair 0.45 - 0.60, Good 0.60 - 0.75, Excellent 0.75 - 1.0)

The average STI values are obtained as 0.49 in Sultan Mosque, and 0.47 in Yeni Mosque and they are considered fair. According to the graphics in Figure 16, receiver points that are located close to the mihrab (R1 and R2 in Yeni Mosque and R5 in Sultan Mosque) reach the best STI values. The lowest values are measured at R9, and R10 in Sultan Mosque located in the women's worship area separated by plastic panels in current use and R3 located behind the mimbar in Yeni Mosque.

EVALUATION OF POSSIBLE ORIGINAL STATES OF THE PRAYER HALLS DEPENDING ON DIFFERENT PLASTERS

Acoustical models of mosques without interventions such as dividing panels and ceramic coverings are used to present their original states. There are 17 scenarios created by applying different plasters defined in Table 2 on mosques' walls and dome surfaces in the simulations. P1 represents the current plaster found by the acoustical measurements; P2, P3 and P4 represent sound absorption coefficients of different current plaster types collected from similar research in literature. P5- P17 represents historical plasters and absorption coefficients of them obtained from the studies of Tavukçuoğlu, et al. 2011 and Bozkurt and Demirkale, 2019.

Figure 17 shows optimum T30 values from the literature and measured reverberation time (T30) values of 17 scenarios. Orfali, Kayılı, Karabiber & Erdoğan recommend optimum T30 values depending on the volumes of mosques for the mid frequencies. To compare the results, optimum T30 values are defined according to the approximate volume of cases, which is 5000 m3. The use of historical plasters decreases reverberation times (T30) in suggested ranges for mosques by previous studies, as expected. In mid frequencies, more suitable T30 values are obtained as the thickness of plasters increases. However, since the plaster thicknesses determined for the plaster type P8, P9, P12, P13, P16, and P17 are 9-12 cm, the application of these plasters on the dome surfaces of the mosques may not be realistic.

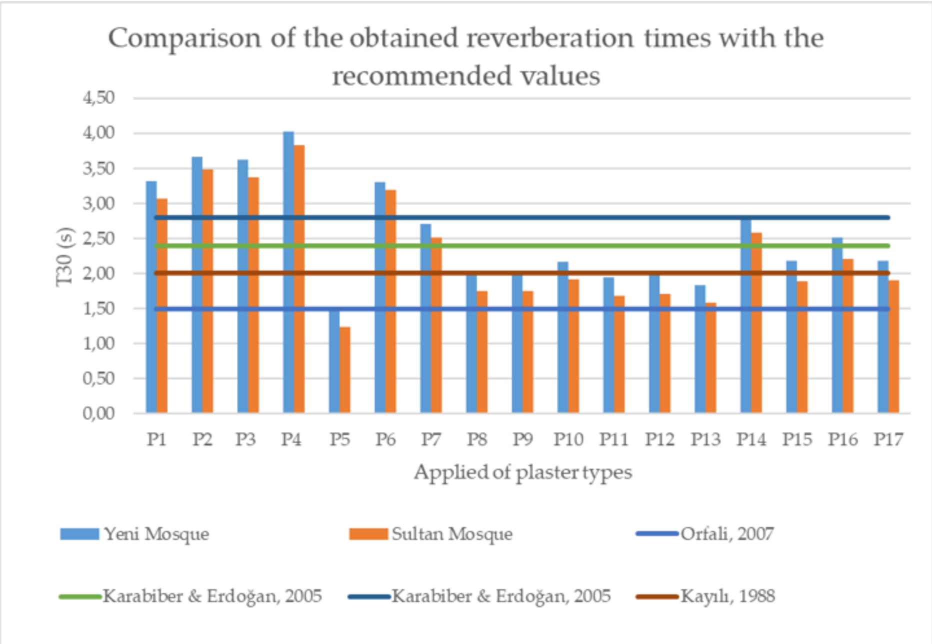


Figure 17 - Simulated T30 (s) values for mid frequencies with different plaster types compared to optimum values for volume of 5000 m3 (●, ●; (Karabiber and Erdoğan, 2002), ●; (Kayılı, 1988), ●; (Orfali, 2007)).

Figure 17 shows that the plaster types can create great differences in the perception of the acoustical environment of the users. These differences can be defined by using JND, which is one of the classic psychoacoustic experiments. Blevins et. al. (2013) defines just noticeable difference (JND) of reverberation time (RT) as *"It quantifies the minimum change in RT that can be readily perceived. … The* *present accepted value for the JND of RT, published in ISO 3382-1, is 5% for reverberation metrics."* When the average reverberation times in the mosques are examined for the volumes where P1, P5 and P11 plasters are applied, quite different values are obtained. In this context, the JND values of the T30 are calculated. The greatest difference will be perceived when the environment transition is made from P1 to P5 or from P1 to P11. 11 JND difference occurs between P1 and P5, and 8 JND difference occurs between P1 and P11.

Table 5 indicates the average values of T30 for 500 Hz and 1000 Hz for the 17 scenarios. Coefficients of variations are calculated to show the differences in T30 values depending on the receiver points for each scenario. The coefficient of variation analysis method, which is expressed as a percentage, is used to determine the larger spread of the variables in the group of variables with different averages of the coefficient of variation and to evaluate the variables within themselves. The coefficient of variation (%) value is obtained by dividing the standard deviation value of the group of variables examined by the arithmetic mean and multiplying the result by 100. If the coefficient of variation value is small, it is interpreted that the value distribution does not move away from the mean values, and if it is large, it is interpreted that the variables move away from the mean values and show a different distribution.

Table 5 - Obtained T30 values from acoustical simulation models with different plaster types. (CV (%); coefficient of variation).

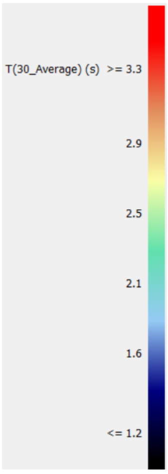
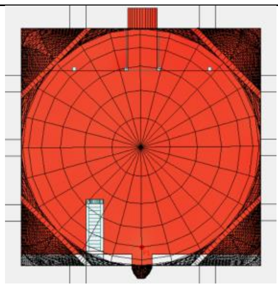
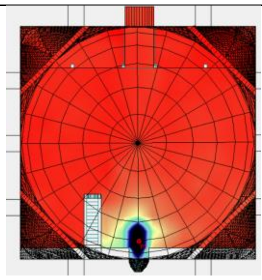
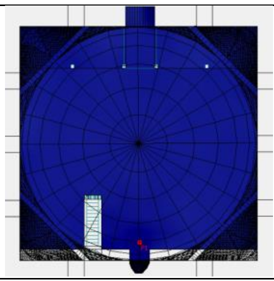
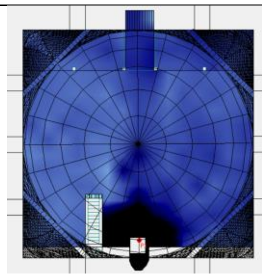
	T 30 (YENİ MOSQUE)			**T 30 (SULTAN MOSQUE)**		
plaster type	**500 Hz**	**1000 Hz**	**CV (%)**	**500 Hz**	**1000 Hz**	**CV (%)**
P1	3.56	3.06	0.31	3.46	2.68	0.45
P2	4.09	3.24	0.32	4.11	2.85	0.33
P3	3.56	3.68	0.42	3.46	3.29	0.43
P4	4.09	3.95	0.45	4.11	3.56	0.34
P5	1.59	1.34	0.26	1.37	1.11	0.69
P6	4.42	2.18	0.28	4.54	1.85	0.32
P7	3.56	1.86	0.27	3.46	1.56	0.32
P8	1.59	2.49	0.13	1.37	2.14	0.45
P9	0.97	3.06	0.41	0.82	2.68	0.49
P10	2.54	1.79	0.12	2.33	1.5	0.44
P11	1.96	1.93	0.39	1.73	1.63	0.57
P12	1.88	2.08	0.25	1.66	1.77	0.58
P13	1.88	1.79	0.32	1.66	1.5	0.7
P14	3.56	2.01	0.25	3.46	1.7	0.31
P15	1.76	2.61	0.19	1.53	2.25	0.36
P16	1.96	3.06	0.17	1.73	2.68	0.35
P17	1.88	2.48	0.17	1.66	2.14	0.43

According to the results of the coefficient of variation values, the values in the Sultan Mosque are mostly higher than in the Yeni Mosque. It can be thought that this difference is due to the differences in the spatial and geometrical characteristics of the examined mosques. The Sultan Mosque can be defined as a couple of volumes with side spaces, while the Yeni Mosque has a single volume shaped under a single dome. According to the obtained CV values, the variation depending on the receiver points for T30 distributions in the volume is not large. Since the minimum and maximum values of the average T30 value range according to the value legend obtained from the Odeon are similar to each other, it is decided to analyze the distribution of T30 over grid maps.

To calculate STI values for many receivers, grid response analysis is used for this study in the absence of a sound reinforcement system. Grid analysis is defined as a useful way for acoustical researchers to see a map of the spatial distribution of acoustical parameters (Rindel, 2001). The dimensions of the grids are arranged as 1.0 x 1.0 m at a height of 0.85 m. Grid response analysis aims to investigate the impact of plaster types on the STI values of Sultan Mosque and Yeni Mosque. The results of current situations and P5, and P11, which gave the best results in terms of T30, EDT and STI parameters, are presented in the grid maps (Table 6-8).

Grid maps of T30 and EDT for Yeni Mosque and Sultan Mosque are given in Table 6 and Table 7. It is seen that the average T30 values are quite low for historical plasters and high for plasters used for the current situation. The minimum and maximum T30 values obtained from the receiver points are also given in the tables. It has been concluded that there are no significant value differences for the T30 parameter between the receiver points. However, the effect of the mimbar on the T30 value distribution can be understood from the grid analysis of the Sultan Mosque. Although T30 values were lower in the area behind the mimbar in the Sultan Mosque, this situation is not valid for every plaster type in Yeni Mosque.

Table 6 - Simulated average T30 and EDT values on grid analysis for Yeni Mosque.

	DISTRIBUTION OF T30 VALUES	**DISTRIBUTION OF EDT VALUES**
		
	P1 (current state) T30min= 3.30 s T30max= 3.33 s	**P1** EDT_{min} = 3.33 s, EDT_{max}= 3.41 s
		
	P5 T30min= 1.46 s T30max= 1.47 s	**P5** EDT_{min} = 1.47 s, EDT_{max}= 1.66 s

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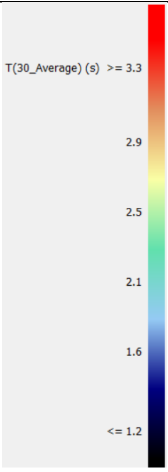
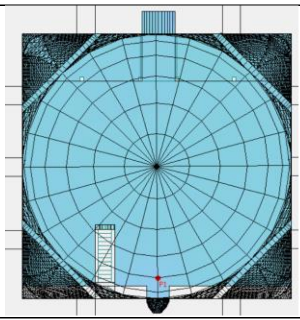
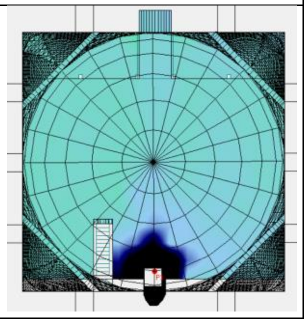
<table>
<tr><td colspan="3">Table 6 continues.</td></tr>
<tr><td rowspan="2"></td><td></td><td></td></tr>
<tr><td>P11
T30min= 1.93 s
T30max= 1.95 s</td><td>P11; EDT_{min} = 1.96 s,
EDT_{max}= 2.08 s</td></tr>
</table>

The difference between the mean values of EDT and T30, and the average EDT_{min} and EDT_{max} values are calculated to be higher in the Sultan Mosque compared to the other case. According to Table 6 and Table 7, it is seen that the distribution of EDT values in the main worship areas of the Yeni Mosque is more balanced compared to the Sultan Mosque. Homogeneous sound distribution and desired intelligibility are obtained more clearly in Yeni Mosque.

Table 7 - Simulated average T30 and EDT values on grid analysis for Sultan Mosque.

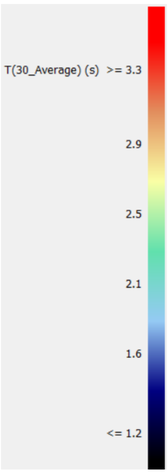
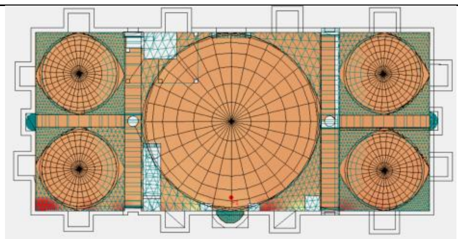
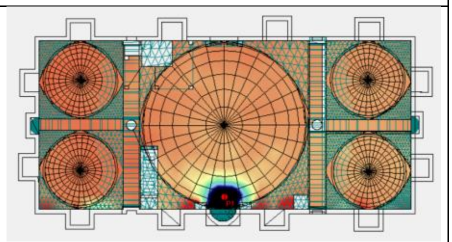
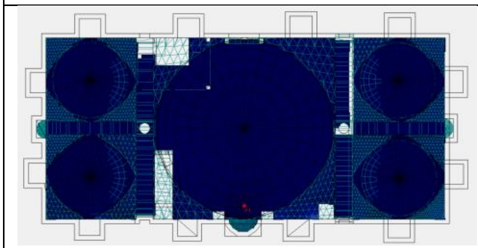
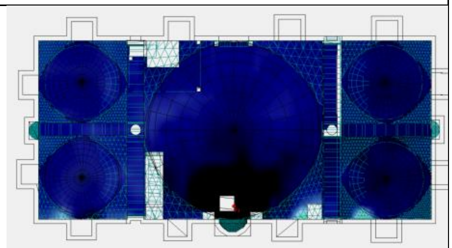
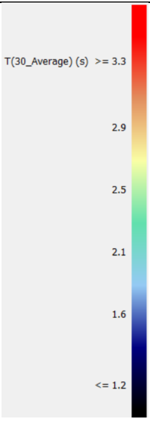
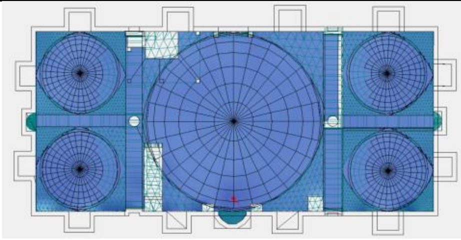
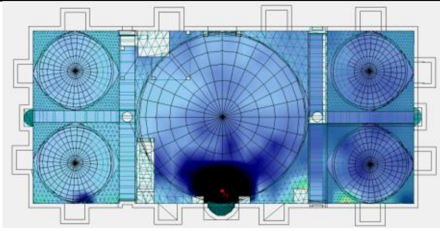
<table>
<tr><th></th><th>DISTRIBUTION OF T30 VALUES</th><th>DISTRIBUTION OF EDT VALUES</th></tr>
<tr><td rowspan="4"></td><td></td><td></td></tr>
<tr><td>P1 (current state); $T30_{min}$ = 3.05 s,
$T30_{max}$= 3.09 s</td><td>P1; EDT_{min} = 2.88 s, EDT_{max}= 3.22 s</td></tr>
<tr><td></td><td></td></tr>
<tr><td>P5; $T30_{min}$ = 1.23 s, $T30_{max}$= 1.26 s</td><td>P5; EDT_{min} = 0.9 s, EDT_{max}= 1.45 s</td></tr>
</table>

Table 7 continues.		
		
	P11; $T30_{min}$ = 1.66 s, $T30_{max}$= 1.69 s	**P11;** EDT_{min} = 1.41 s, EDT_{max}= 1.9 s

Average STI values in Yeni Mosque were obtained as 0.45 (P1), 0.42 (P2), 0.44 (P3), 0.43 (P4), 0.56 (P5), 0.46 (P6), 0.45 (P7), 0.47 (P8), 0.47 (P9), 0.49 (P10), 0.50 (P11), 0.51 (P12), 0.50 (P13), 0.45 (P14), 0.48 (P15), 0.48 (P16), 0.54 (P17) and in Sultan Mosque were obtained as 0.49 (P1), 0.46 (P2), 0.47 (P3), 0.47 (P4), 0.62 (P5), 0.50 (P6), 0.48 (P7), 0.51 (P8), 0.51 (P9), 0.54 (P10), 0.55 (P11), 0.56 (P12), 0.61 (P13), 0.48 (P14), 0.52 (P15), 0.52 (P16), 0.59 (P17) respectively.

The current situation and the historical plaster samples that gave the best results were included in the analysis made on the grid plans. According to this, in P5 and P11, fewer areas with poor STI quality and lower CV (%) values than the other simulated materials are observed. The CV (%) values in the Sultan Mosque are concluded as higher than in the Yeni Mosque. It can be said that the differences in STI values between receivers are higher in Sultan Mosque. In the current situation, areas that were determined to be weak in terms of STI improved in P5 and P11 and reached "fair" levels. In the case of P11, which is one of the plasters that give the best STI values, the effect of the mimbar is still understood on the grid plans for both mosques (Table 8).

Table 8 - Simulated average STI values for mosques on grid analysis. (CV (%); coefficient of variation).

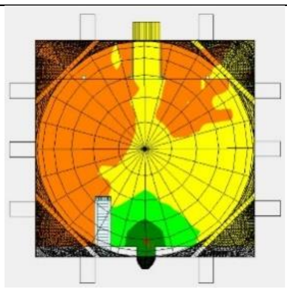
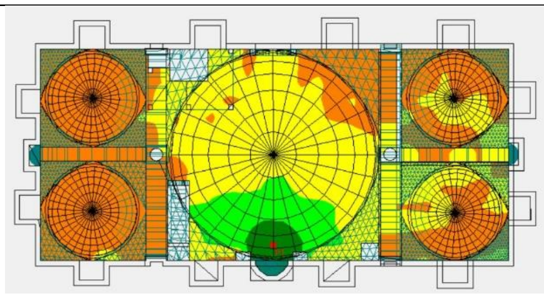
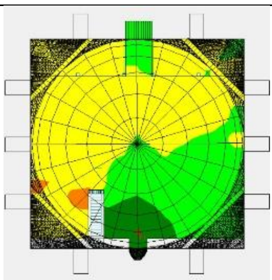
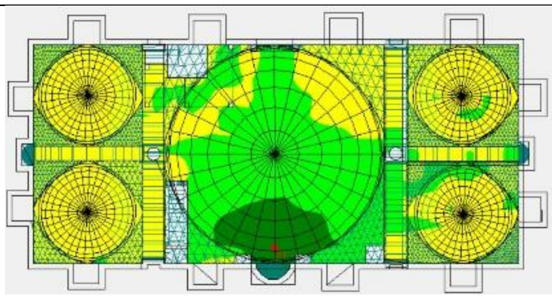
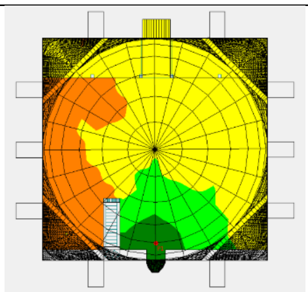
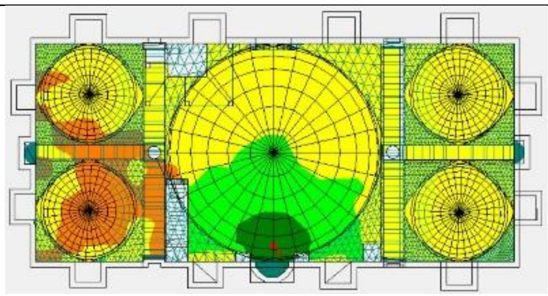
DISTRIBUTION OF STI VALUES • Bad 0 - 0.32, • Poor 0.32 - 0.45, • Fair 0.45 - 0.60 • Good 0.60 - 0.75, • Excellent 0.75 - 1.0	
YENİ MOSQUE	**SULTAN MOSQUE**
	
P1 (current state) CV (%)= 12.65	**P1 (current state)** CV (%) = 19.31

Table 8 cntinues.	
	
P5 CV (%)= 12.18	**P5** CV (%) = 13.89
	
P11 CV (%)= 11.9	**P11** CV (%) = 16.4

CONCLUSIONS

Historical worship spaces like mosques in the study contain a unique and dynamic record of human activity for Centuries and each generation tried to therefore shape and sustain the historic environment. As a result, mosques have had several changes/interventions, and which are difficult to identify the exact construction date, during restoration works. Consolidation of the building has priority in most of the restoration process. However, the term 'building' goes beyond physical form, to involve all the characteristics that can contribute to a 'sense of the building' (Drury and McPherson, 2008). For that reason, the conservation of historical mosques is found related to acoustical concepts as well as visual concepts. The conservation of original acoustical conditions is another important issue to have a perception of historical mosques. However, there is not enough study in the literature to regain the sound environment of the period when they were first built, because of the possible interventions they had during their lifetime.

The study focused on the change in material properties especially the content of the plasters which were applied during restoration works throughout the history of mosques. Because it is found that the absorption coefficients of the plasters in the current state of the mosques are similar to today's cement-based contemporary mortars. This issue also underlined by the other studies in the literature, revealing the dome and the wall surfaces of historical buildings in the Ottoman period were covered by plasters that had different characteristics (İpekçi, et al., 2019, Sü Gül, 2019). And it is concluded that the original mortars could be differentiated for both cases of the study and they might sound very different when the time they were first built.

- When transitioning from current state mosque environment (P1 plaster is used) to original environment (historical plasters no:P5 and no:P11 are used), users will easily be able to perceive that both environments have different acoustical characters.

- While the acoustical field results for current states of cases are not closed to the optimum values suggested in the literature, historical plasters provide more desired environments for both acoustic functions as speech and music.

- The distributions of acoustical objective parameters become more uniform with historical plasters. The variations depending on the receiver points are further reduced, especially in parameters related speech, and provides more equitable conditions for the entire congregation. All these results reveal the difference that the original content of the plasters creates not only for visual but also for auditory perception.

In this context, it has been revealed that the mosques may not have original plasters with the acoustic data obtained with the current situation measurements. This outcome can raise the question; of whether it is possible to comment on the originality of materials of a historical space by identifying its current acoustical character.

To have more certain comments on this issue; the study should be widened with more materials and scenarios. For this purpose, by taking samples from historical plaster surfaces and determining their sound absorption characteristics, the applicability of plasters with similar properties in renovation works can be ensured. It may be necessary to repeat more plaster samples, in more mosques, and in different volumes. Also, the carpet surfaces, which have an effective surface area like plaster surfaces, are expected to significantly affect the acoustical environment of mosques. In further studies, sound absorption coefficients for carpet surfaces can be analyzed together with historical plasters, and the change of T30 values for music and speech functions according to the carpet types can be examined.

For the sustainable conservation of the historical environment; it is important to keep the status of historical mosques with original values. The relevant disciplines striving to create a suitable acoustic environment in mosques can benefit from this study which insight into the selection of appropriate materials for historical mosques during the restoration projects. For that reason, maintaining the original acoustic environment of the prayer hall for the users should be an evaluation criterion for the field of conservation. Therefore, the data obtained from the present study can be used for mosques that are in the restoration process.

Conflict of Interest Statement

There is no conflict of interest for conducting the research and/or for the preparation of the article.

Financial Statement

No financial support has been received for conducting the research and/or for the preparation of the article.

Ethical Statement

All procedures followed were in accordance with the ethical standards.

Copyright Statement for Intellectual and Artistic Works

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Author Contribution Statement

A. Fikir / Idea, Concept	B. Çalışma Tasarısı, Yöntemi / Study Design, Methodology	C. Literatür Taraması / Literature Review
D. Danışmanlık / Supervision	E. Malzeme, Kaynak Sağlama / Material, Resource Supply	F. Veri Toplama, İşleme / Data Collection, Processing
G. Analiz, Yorum / Analyses, Interpretation	H. Metin Yazma / Writing Text	I. Eleştirel İnceleme / Critical Review

AUTHOR 1: A/B/C/D/F/G/H/I
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